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RESEARCH ARTICLE

Reproductive Biology and Stock Status of Shortfin Scad, *Decapterus macrosoma* (Bleeker, 1851) in the Southwest Sulu Sea, Palawan

Lenie M. Gonzales*, Myrna B. Candelario, Herminie P. Palla, Elmar M. Villaflor

Department of Agriculture, Bureau of Fisheries and Aquatic Resources, MIMAROPA, National Stock Assessment Program, Brgy. Sta. Monica, Puerto Princesa City, 5300 Palawan, Philippines

ABSTRACT

The shortfin scad *Decapterus macrosoma* is a major small pelagic resource in Palawan and a key contributor to landings in the Southwest Sulu Sea. This study evaluated its reproductive biology, population dynamics, and length-based stock status using National Stock Assessment Program (NSAP) monitoring data collected from commercial landings in Narra and Brooke's Point, Palawan, from January 2018 to December 2020. A total of 7,525 specimens caught by bagnet and ringnet were measured for total length and weight, and gonads were examined to determine sex and maturity stage; spawning seasonality was inferred from monthly maturity-stage frequencies and gonadosomatic index (GSI), while length at first maturity (L_{50}) was estimated using a logistic model. Growth and mortality parameters were derived using FiSAT II, and stock condition was assessed through exploitation indices, yield- and biomass-per-recruit analyses, LBSPR (SPR), and Froese length-based indicators. Among sexed individuals, females were significantly more abundant than males (overall ratio 1:1.17). Reproductive activity was seasonal, with peak spawning consistently occurring in April–May, supported by elevated proportions of ripe females and the highest monthly mean GSI (up to 3.03 in May). Female L_{50} was estimated at 15.81 cm TL. Gear selectivity indicated early capture, particularly in bagnet (Lc_{50} = 14.08 cm) relative to L_{50}, while ringnet selectivity (Lc_{50} = 15.68 cm) was near maturity length. Estimated natural mortality (M) ranged from 1.75 to 1.88 yr^{-1}, whereas fishing mortality was high (F = 2.71 for bagnet; 3.17 for ringnet), resulting in exploitation rates of 0.61–0.64 that exceed the precautionary threshold (E = 0.5). Spawning potential ratios were low (SPR = 22% for bagnet; 26% for ringnet), and Froese indicators showed persistently low proportions of mature fish (10.4–28.9%) and mega-spawners (3.6–9.4%), indicating recruitment and growth overfishing with severe size truncation. These findings support strengthened management through improved size selectivity and strict enforcement of minimum mesh regulations, alongside protection of spawning stocks during the April–May peak reproductive period.

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1. INTRODUCTION

The shortfin scad, *Decapterus macrosoma* (Bleeker, 1851), locally known as *galunggong*, is a small pelagic species belonging to the family Carangidae. It plays a critical role in Philippine fisheries as one of the most abundant and economically significant roundscad harvested nationwide. Its year-round availability in both municipal and commercial fishing grounds contributes to its continued exploitation and market importance (Calvelo 1992; Pastoral et al. 2000; Sangalang and Quinay 2015). Regionally, *D. macrosoma* is also commercially valuable throughout Southeast Asia (Borsa, 2003).

Despite its continued contribution to national landings, fisheries statistics indicate a declining trend in roundscad production from 2013 to 2017 (DA-BFAR 2019). Although annual reductions were modest (0.05% in 2016 and 0.04% in 2017; Santos et al. 2017), the sustained downward pattern warrants precautionary assessment.

Based on NSAP data, *D. macrosoma* comprised approximately 15% of the recorded catch in the Southwest Sulu Sea from 2018 to 2020, ranking as the second most dominant species in the area (Figure 1). Its consistent contribution to catch composition

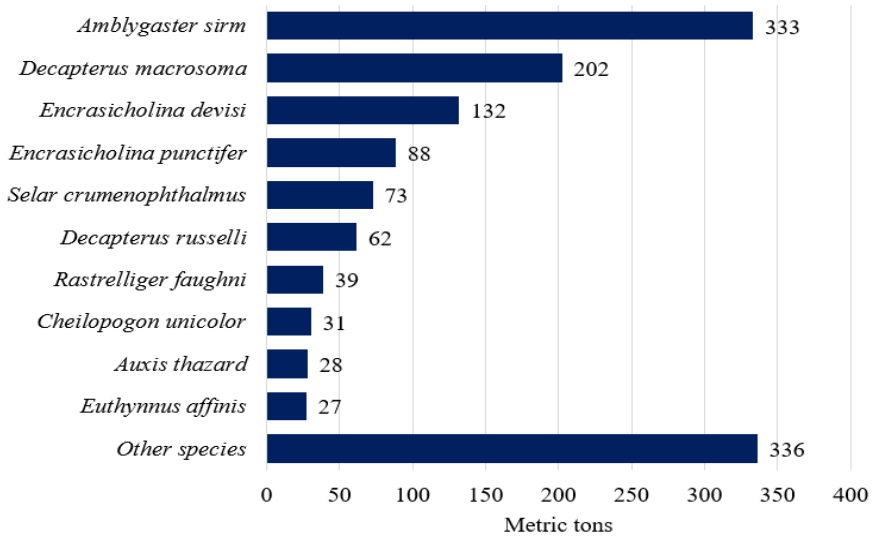

Figure 1. Top species caught in the Southwest Sulu Sea, Palawan, from January 2018 to December 2019.

reflects both ecological importance and sustained fishing pressure.

The species is primarily harvested using bagnet (BN) and ringnet (RN) gears, which are designed to target schooling pelagic fishes. While effective, intensive exploitation using these gears may reduce spawning biomass if not supported by biologically informed management.

Biological indicators such as gonadal maturity stages and length at first maturity have been instrumental in fisheries regulation. These indicators supported the establishment of Joint Administrative Order No. 01, series of 2015, which implemented a closed fishing season for roundscad in Northeastern Palawan (DA-DILG 2015). However, similar regulatory measures are not in place in the Southwest Sulu Sea despite a decline in landings from 548 metric tons in 2015 to 500 metric tons in 2020.

This study aims to evaluate the reproductive biology, population dynamics, and length-based stock indicators of *D. macrosoma* in the Southwest Sulu Sea to provide scientific evidence needed for sustainable fisheries management.

2. MATERIALS AND METHODS

2.1 Study area and sampling

Fish samples were collected in the identified landing sites in Barangay Calategas, Panacan 1 and 2, Narra, and Barangay Poblacion, Brooke's Point, Palawan (Figure 2). These landing sites are located along the southeastern coast of Palawan facing the Sulu Sea, one of the major marine bioregions of the Philippines (Asian Development Bank 2014). The majority of residents in Narra and Brooke's Point rely primarily on fishing as their main livelihood.

Records of the landings of fish species, including *D. macrosoma*, are collected regularly throughout the year by teams of research enumerators of the National Stock Assessment Program (NSAP) of the Bureau of Fisheries and Aquatic Resources - MIMAROPA (BFAR-MIMAROPA) and the National Fisheries Research and Development Institute (NFRDI). Among the roundscad species caught in these waters, *D. macrosoma* was the most dominant and abundant, followed by *D. russelli*. This fishery is a main source of income for the coastal communities of Narra and Brooke's Point, Palawan, two municipalities in Southwest Palawan. Fishers used a bagnet, locally known as "basnigan," and a ringnet, locally known as "pangulong".

2.2 Data sources

This study utilized the reproductive biology data of *D. macrosoma* collected for 36 months from January 2018 to December 2020 by the NSAP team at the established fish landing site in the municipalities of Narra and Brooke's Point, Palawan. A total of 7,525 individual fish samples were obtained from commercial fishing vessel catches. Of these, 3,483 specimens were collected from ringnet operations and 4,042 from bagnet fishing gears in landing areas of Brgy. Calategas and Panacan 1 and 2 in Narra and Brgy. Poblacion in Brooke's Point, Palawan.

The collection of fish samples was conducted at intervals throughout the month, depending on the availability of the target species. Sample sizes were randomly selected to represent a range of size classes.

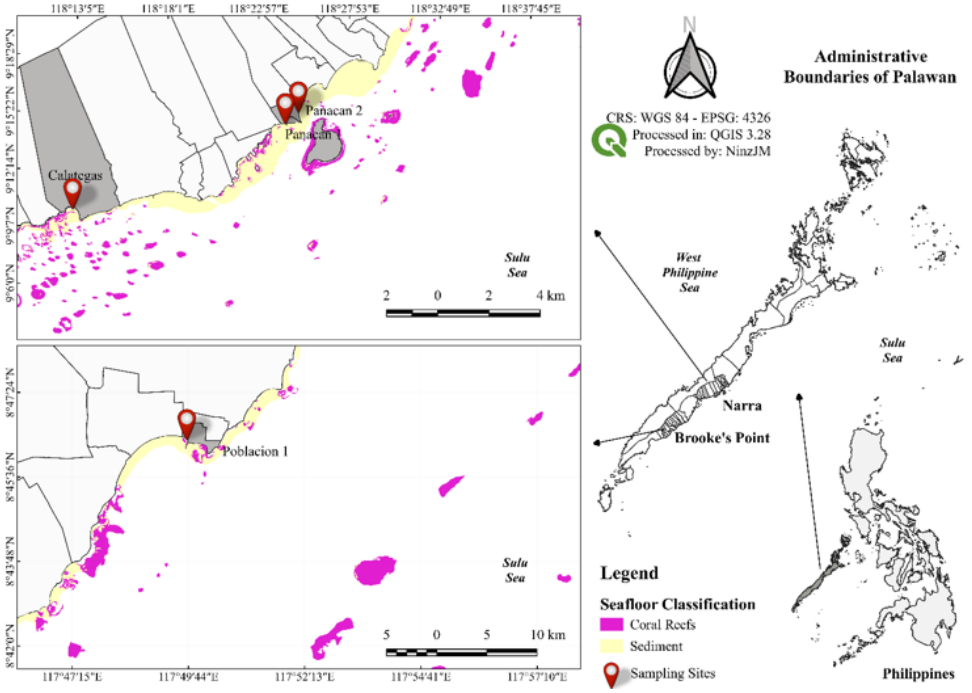

Figure 2. Map of Brgy. Calategas, Panacan 1 and 2, Narra, and Brgy. Poblacion, Brooke's Point, Palawan, showing the fish landing sites and the coastal habitat in the area.

Specific sampling dates were not predetermined, as the purchase of specimens depended on actual landings. Moreover, the fishing activities of the commercial vessels, which served as the primary source of samples, were influenced by lunar cycles (full-moon break) and prevailing weather conditions.

2.3 Biological data collection

A total of 7,525 fish samples were collected from 2018 to 2020: 4,017(53.38%) samples in 2018, 2,630 (34.95%) samples in 2019, and 878 (11.67%) samples in 2020. The weight of each fish sample was measured using a portable weighing scale to the nearest 0.1 grams, whereas the total length (TL) was measured using a measuring board, from the tip of the snout to the tip of the tail, using a ruler to the nearest centimeter.

The fish samples were dissected to determine the sex and maturity stages. Macroscopic determinations of gonadal stages were done following the Five-Point Scaling Method used by İşmen (2003) (Table 1). This study used abbreviations to represent the gonad stages (U, I, II, III, IV, V). The weight of the male and female gonads was measured using a digital weighing scale to the nearest 0.01 gram to compute the Gonadosomatic Index (GSI).

Table 1. Five-point scaling method.

Maturity Stages	Classification	Distinguishing Characteristics
Juvenile (U)	Juvenile	Young individuals have not yet engaged in reproduction; fish samples are very small.
Stage I (I)	Immature/Virgin	Gonads are very small and negligible for female; threadlike for the male.
Stage II (II)	Developing/Maturing	Sexual products have not yet begun to develop; gonads are very small in size; eggs are not distinguishable to the naked eye.
Stage III (III)	Mature/ Developed	Female- Eggs are distinguishable to the naked eye; a very rapid increase in the weight of the gonads is in progress. Male- testes change from transparent to pale rose color.
Stage IV (IV)	Gravid and Spawning	Sexual products are ripe; gonads have achieved their maximum weight; sexual products are extruded in response to light pressure on the belly; the weight of the gonads decreases rapidly from the start of the spawning to its completion.
Stage V (V)	Spent or Resting	The sexual products have been discharged; the genital aperture is inflamed; gonads have the appearance of deflated sacs; the ovaries contain a few leftover eggs and the testes have some residual sperm. Finally, in the resting stage, inflammation on the genital aperture has subsided; gonads are very small; and the eggs are not distinguishable to the naked eye.

A Log sheet was used to record the necessary data, including sample source, landing center, date of sampling, fishing gear source, fishing ground, scientific name, individual length and weight, sex, gonadal stage, and GSI. The completed log sheet forms were included in the monthly reports of the research enumerators assigned to the fish landing sites and submitted to the NSAP Office for data encoding and processing by the Data Analyst.

2.4 Data processing and analysis

The process includes strict data examination and evaluation, error tracking, data editing, reconciliation, sorting, and filtering using pivot table routines. The data were usually pooled by month before analysis.

2.4.1 Sex ratio

Knowledge of the sex ratio of fish is important to ensure proportional fishing of both sexes and provides information needed to assess a population's reproductive potential and strength. Studies have shown that sex ratio indicates the abundance of one sex at a particular time throughout the year (Jega et al. 2017). Sex ratio (male: female) was evaluated using the Chi-square Test (X^2) (Pearson 1992), following the formula: 1990), following the formula:

$$\mathbf{x^2 = \Sigma \frac{(O - E)^2}{E}}$$

where O is the observed frequency, and E is the expected frequency, to test the hypothesis as follows:

$H_{0:}$ There is no significant difference between male and female abundance (sex ratio not significantly different from 1:1).

$H_{1:}$ There is a significant difference between male and female abundance (sex ratio ≠ 1:1).

2.4.2 Spawning period

Identifying fish spawning areas and periods is critical for understanding population dynamics and establishing effective management strategies for fishing activities targeting spawners. Spawning periods were identified based on the peak proportion of ripe (Stage IV) females and elevated GSI values. Fishes that aggregate to spawn are the target to catch (Erisman et al. 2017).

The spawning period was determined based on the different phases of gonadal maturity and GSI. Relative gonadal frequency distribution was done on a monthly basis. Gonadal maturity stages were tabulated as the count of female samples per stage. The number of samples for all stages was totaled, and the percentage for every stage per month was computed.

The GSI was computed using the weight of the gonads (Borthakur 2018), following the formula: **GSI = GW/BW x 100,** where GW is the gonad weight, and BW is the total weight with intact gonads. Monthly data were plotted in a graph. The highest percentage distribution of gonadal maturity stages and GSI was identified and suggested as the spawning season.

2.4.3 Length at first maturity (L_m)

Length at first maturity (L_m) or (L_{50}) is a crucial tool for managing and conserving fish populations. It is a parameter that describes the individual body size at which 50% of a population is mature. One of the most critical aspects of management is the size at first sexual maturity. Understanding the value of first maturity is essential as a baseline for the species' age and mortality (Pardo et al. 2022).

The total length at which 50% of all sexually mature individuals (L_{50}) was estimated from the proportion of mature individuals in each 0.5 cm length class interval and the fitted logistic curve (Sparre and Venema 1992), as follows:

$$\mathbf{P = 1/1 + exp^{(S_1 + S_2 x L)}}$$

where P is the proportion of mature individuals within a length class, S_1 is the intercept, S_2 is the slope, and *L* is the midpoint length. Corresponding weight at first maturity was computed and fitted using the linear equation $W=aL^b$; where W is the estimated weight at first maturity, *a* is the intercept, *b* is the slope, and *L* is the computed length at first maturity.

2.4.4 Population parameters

In fisheries management decisions, population parameters with unique dynamics, such as growth, mortality, and recruitment patterns, obtained through long-term data and standardized methods, are essential for providing the necessary information. Continuous monitoring of the species helps in understanding the trends of the species population (Pope et al. 2010).

Length-frequency datasets from all samples were used in the analysis. To improve cohort resolution in the Von Bertalanffy Growth Function (VBGF) and facilitate clearer interpretation, the data were consolidated into a two-year dataset (2018–

2019), separated by gear type (Bagnet and Ringnet). The 2018–2019 dataset was pooled to improve cohort resolution and reduce sampling variability in 2020. These datasets were then imported into the FAO-ICLARM Fish Stock Assessment Tool (FiSAT II) software (version 1.2.2) to generate growth curves and estimate key population parameters.

FiSAT II software includes routines for estimating parameters of the von Bertalanffy Growth Function (VBGF) and other population dynamics. The primary outputs derived from FiSAT include growth parameters (asymptotic length L_{∞}, growth coefficient k, and growth performance index φ′); recruitment pattern (indicating strong and weak recruitment pulses); mortality rates (total mortality Z, natural mortality M, fishing mortality F, and exploitation rate E); probabilities of capture (lengths at which 25%, 50%, and 75% of the population are captured – L_{25}, L_{50}, L_{75}).

The first step in estimating growth parameters was determining L_{∞} using the Powell-Wetherall method based on the Beverton and Holt (1956) equation:

$$Z = k(\frac{L\infty - L}{L - L'})$$

Where Z is total mortality, k is the growth coefficient, L is mean length, L_{∞} is the asymptotic length, and L′ is the initial length of the sample.

The estimated L_{∞} was then verified using the ELEFAN I (Electronic Length Frequency Analysis) module within FiSAT, which uses length-frequency data to scan for optimal values of L_{∞} and k. These parameters were applied in the von Bertalanffy Growth Equation (von Bertalanffy 1934):

$$L_t = L\infty\left(1 - e^{-k(t-t_0)}\right)$$

Where L_t is the length of the fish at age t, e is the base of the natural logarithm, and t_0 is the theoretical age at which fish length is zero.

Total mortality was partitioned into natural mortality and fishing mortality using the equation:

$$Z = M + F$$

Natural mortality was calculated using Pauly's empirical formula (Pauly, 1984):

$$Log\ M = 0.654 Log\ k - 0.28 Log\ L\infty + 0.463\ Log\ T$$

Where (Temperature) T is the annual mean habitat temperature (28°C). From these values, the exploitation rate was calculated as:

$$E = F/Z$$

Recruitment patterns were estimated by backward projection of length-frequency data using FiSAT routines. This involved projecting adjusted frequencies onto the time axis based on growth intervals (Δt\Delta tΔt), refining recruitment peaks; summing adjusted frequencies for each month; normalizing by subtracting the lowest monthly sum; and presenting monthly relative recruitment as a percentage of total annual recruitment.

Probabilities of capture were estimated by extrapolating the descending limb of the catch curve to account for unobserved fish that were available but not caught. This was computed using:

$$P_i = ln(N_i/\Delta t) ln(N_{ai}/\Delta t)$$

where P_i is the probability of capture at length class *i*, N_i is the observed number of individuals caught, N_{ai} is the estimated number of individuals available, and Δt is the time interval required to grow through a length class.

Yield-per-Recruit (Y/R) and Biomass-per-Recruit (B/R) analyses were carried out using FiSAT II developed by the Food and Agriculture Organization of the United Nations. These analyses follow the Beverton and Holt yield-per-recruit model, which evaluates the effects of fishing pressure and size at first capture on the yield and biomass contributed by each recruit entering the fishery.

The analyses were performed separately for each gear type using their corresponding parameters (L_{∞}, K, M, and Lc). The ratio of Lc/L_{∞} and a range of fishing mortality (F) values were used to generate curves of relative yield (Y/R) and biomass (B/R) per recruit.

To assess the potential effects of mesh-size regulation, simulations were conducted by increasing L_c by 10 %, 20 %, and 30 % relative to the current values. The resulting Y/R and B/R curves were compared to evaluate how changes in L_c/L_{∞} could affect yield and spawning biomass. These analyses provided the basis for evaluating current exploitation levels and recommending suitable management measures to ensure the sustainability of the stock.

2.4.5 Other length-based models

The Length-based Spawning Potential Ratio (LBSPR) model was developed to estimate the Spawning Potential Ratio (SPR) using length-frequency data alone (Hordyk et al. 2015). SPR measures the proportion of unfished reproductive capacity remaining in a population under fishing pressure (Walters and Martell 2004). An SPR of 100% indicates an unfished stock, while 40% is considered a management target, and 20% is a limit reference point below which recruitment may be impaired (Mace and Sissenwine 1993).

The LBSPR model requires four key inputs:

- M/K ratio
- Asymptotic length (L_∞)
- Length at maturity (L50 and L95)

These values are then entered into the Barefoot Ecologist's Toolbox website (Prince et al. 2015). The CSV (comma-separated values) file containing length data for female fish in gonad stages 2 to 5 was uploaded to the toolbox**.** The model also estimates size selectivity (SL_{50}, SL_{95}) using a multinomial negative log-likelihood approach (ICES 2018). LBSPR assumes von Bertalanffy growth, constant adult natural mortality, a normal length-at-age distribution, and logistic selectivity (Hordyk et al. 2016).

The Mean Length method (LBAR) was applied to estimate fishing mortality (F) using length-frequency data and species-specific life history parameters. This method is based on the concept that fishing pressure reduces the mean size of individuals in a population (Beverton and Holt 1993; Ault et al. 1996). Only fish that are fully selected by the fishing gear, those between the length at full selectivity (L_c) and the asymptotic length (L_∞), were included in the calculation.

The length at full selectivity (L_c) was identified as the modal length from the length-frequency distribution. Fish lengths between L_c and L_∞ were used to compute the mean length of the exploited portion of the population (LBAR) as:

$$LBAR = \frac{\sum(L_i \cdot f_i)}{\sum f_i}$$

Where L_i is the midpoint of each length class, and f_i is the frequency of fish in that class.

Total mortality (Z) was then estimated using the Beverton-Holt equation:

$$Z = \frac{k(L\infty - LBAR)}{LBAR - Lc}$$

Fishing mortality (F) was obtained by subtracting natural mortality (M) from Z:

$$F = Z - M$$

All computations were performed in Microsoft Excel, following methods developed by Ault et al. (1996, 2005) and FAO (2003). Life history parameters such as M, k, and L_∞ were estimated in this study.

2.4.6 Froese indicator

The length-based indicators of Froese (2004) were applied to assess the stock status of *D. macrosoma,* using length-frequency (LF) data generated in this study. These indicators diagnose recruitment overfishing, growth overfishing, and truncation of large spawners based solely on the size composition of the catch. Length-frequency data were grouped into 1-cm intervals. Biological reference parameters including asymptotic length (L_∞), growth coefficient (k), and natural mortality (M) were derived from the FiSAT II analysis conducted in this study. The length at first maturity (L_m) was obtained from reproductive assessment results.

The optimum length (L_{opt}), defined as the length at which cohort biomass is maximized, was estimated following Beverton (1992):

$$L_{opt} = L\infty \times \frac{3}{3+M/k}$$

Percentage of Mature Fish in the Catch. Individuals were considered mature when total length (TL) was equal to or greater than Lm.

$$\%\ Mature = \left(\frac{N_{TL \geq L_m}}{N_{total}}\right) \times 100$$

where $N_{TL \geq L_m}$ is the number of individuals ≥ Lm and N_{total} is the total sample size.

The target reference value is 100%, indicating that individuals are allowed to spawn at least once before capture. Values substantially below this threshold suggest recruitment overfishing.

Percentage of Fish at Optimum Length

Fish within ±10% of L_{opt} were classified as being at optimum size:

$$0.9L_{opt} \leq TL \leq 1.1\ L_{opt}$$

$$\%\ Optimum\ Length = \left(\frac{N_{0.9L_{opt} \leq TL \leq 1.1L_{opt}}}{N_{total}}\right) \times 100$$

The target reference value is 100%. Low percentages indicate growth overfishing, meaning individuals are harvested before reaching biomass-maximizing size.

Percentage of Mega-Spawners

Mega-spawners were defined as individuals larger than 110% of Lopt:

$$TL > 1.1\ L_{opt}$$

$$\%\ Mega - spawners = \left(\frac{N_{TL > 1.1L_{opt}}}{N_{total}}\right) \times 100$$

In the absence of maximum size regulations, 30–40% mega-spawners indicate a healthy size structure, whereas values below 20% suggest age truncation and reduced reproductive resilience.

Fisheries in many tropical and developing nations continue to face persistent challenges associated with overexploitation and unsustainable harvest practices (Sadovy 2001; Pauly et al. 1998). These issues are further compounded by limited data availability, the multi-species nature of tropical fisheries, and inadequate management measures,

all of which constrain effective assessment and management. Although fisheries science has developed increasingly sophisticated stock assessment models over the past century, these approaches often demand extensive datasets and advanced analytical expertise. Consequently, their applicability remains limited in data-poor contexts such as the Philippines. To address these constraints, simpler and more practical assessment tools have been developed. Among these, the length-based indicators proposed by Froese (2004) provide a valuable and accessible alternative by using length-frequency data to evaluate stock status through the proportions of mature individuals, fish at optimal length, and large "mega-spawners" in the catch.

Length size composition

The length frequency data of the sampled fishes were measured using the total length of the fish. This was used to determine the percentage of mature individuals from the total catch based on the length at first maturity of the species.

3. RESULTS

3.1 Sex ratio

Of the 7,525 specimens examined, 1,653 (22%) were males, 1,941 (26%) were females, and 3,931 (52%) were undetermined due to undeveloped or macroscopically indistinguishable gonads. Sex ratio analysis was performed only on individuals with identifiable gonads to minimize bias.

The overall sex ratio (male:female) was 1:1.17. A Chi-square test revealed significant deviation from parity ($\chi^2 = 42.17$, $p < 0.05$), indicating female dominance. The high proportion of undetermined individuals likely reflects recruitment pulses and early maturity stages. Monthly analysis showed relatively balanced ratios in January, April, and May, while March and November showed more pronounced female dominance. The Chi-square test revealed a statistically significant deviation, confirming that females were significantly more abundant than males during the study period.

The high proportion of undetermined individuals likely represents juvenile or early-maturing fish, consistent with the substantial recruitment component observed in the length-frequency analysis.

3.2 Spawning period

A total of 1,941 female *D. macrosoma* samples were used in the analysis of gonadal maturity stages (Figure 3) and for computing the GSI (Figure 4). Males and undetermined samples were excluded from the computation.

In 2018, *D. macrosoma* exhibited a well-defined reproductive pattern. Early in the year, especially in January, most of the female fish were still immature, likely representing younger individuals or those recovering from the previous year's spawning. As the months progressed into March and April, more fish began moving into the developing and mature stages. By May, a noticeable peak in ripe females was observed, with Stage 4 indicating that this marked the height of the spawning season. This is also supported by the highest gonadosomatic index (GSI) of the year, recorded at 3.03 in May, indicating that the gonads were at their fullest relative to body size. After May, both the number of ripe individuals and GSI values dropped off, suggesting that spawning had largely finished. Very few fish were recorded in the spent stage, which could mean that either the post-spawning phase is short or those individuals were not sampled often.

Table 2. Ratio of male to female *D. macrosoma* from the fish landing sites in Narra and Brooke's Point, Palawan from January 2018 to December 2020.

MONTH	MALE	FEMALE	UNDETERMINED	RATIO	X^2
January 2018–2020	8	8	935	1:1	0.10
February 2018–2020	223	257	693	1:1.15	0.04
March 2018–2020	192	320	841	1:1.67	14.87
April 2018–2020	224	214	221	1:0.96	4.67
May 2018–2020	255	251	142	1:0.98	3.95
June 2018–2020	167	216	82	1:1.29	0.88
July 2018–2020	148	188	86	1:1.27	0.51
August 2018–2020	167	135	552	1:0.81	10.53
September 2018–2020	174	202	216	1:1.16	0.01
October 2018	62	86	93	1:1.39	1.00
November 2018	33	64	70	1:1.94	5.60
December 2018–2020					
TOTAL	**1653**	**1941**	**3931**	**1:1.17**	**42.17**

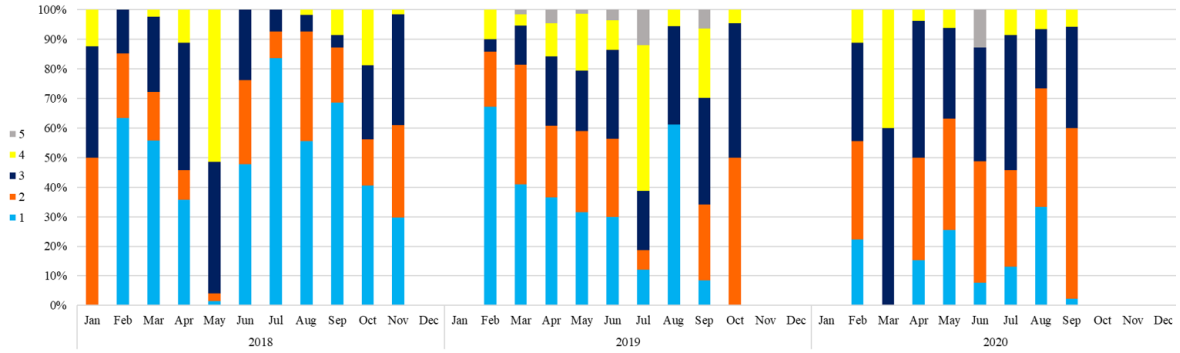

Figure 3. Gonadal maturity stages of female *D. macrosoma* from the fish landing sites in Narra and Brooke's Point, Palawan from January 2018 to December 2020.

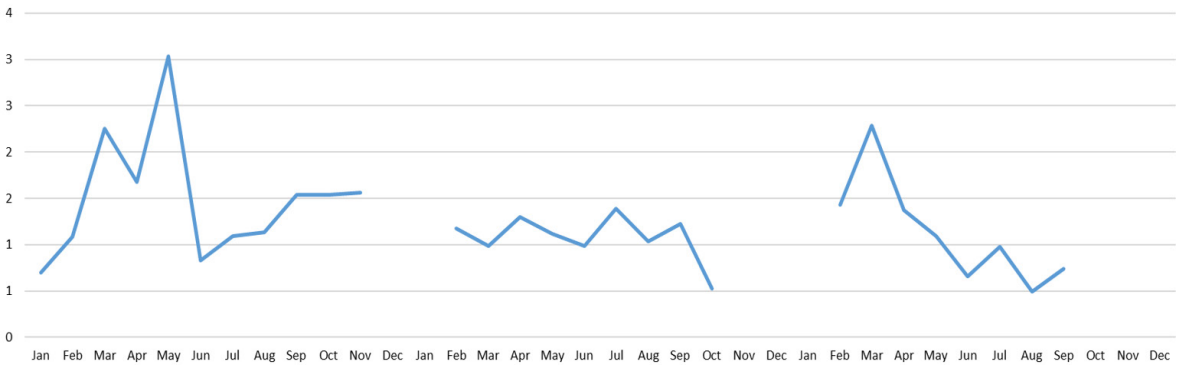

Figure 4. Monthly mean GSI of female *D. macrosoma* from the fish landing sites in Narra and Brooke's Point, Palawan from January 2018 to December 2020.

In 2019, reproductive activity showed a more prolonged distribution than in 2018. A high proportion of immature females was observed during January–February, followed by progressive maturation toward a spawning peak in May. It was also observed that the sex ratio between males and females was at its peak (more females) during March (minor peak in August), three months prior to the peak of spawning in May. However, the recruitment pattern analysis derived from FiSAT for *D. macrosoma* showed two distinct recruitment pulses under both gear types, although their timing and intensity varied slightly. For bagnet, the major recruitment pulse occurred during March-April, while a minor pulse was detected between July-August. In contrast, for ringnet, the major recruitment pulse was also observed during July-August, but the secondary pulse appeared to extend slightly later, from January-February (Figure 5).

These recruitment pulses correspond closely with the observed gonadosomatic index (GSI) and gonadal maturity stages. The highest GSI values recorded in May marked the peak of the spawning season, which was followed by the major recruitment pulse one to two months later, indicating the entry of newly spawned individuals into the fishable population. The minor recruitment pulse during the first quarter of the year coincided with the early presence of mature individuals, suggesting limited or secondary spawning activity during this period. Overall, the results indicate that *D. macrosoma* exhibits a seasonal reproductive cycle, with a primary spawning and recruitment period during the late dry to early southwest monsoon season, consistent across both gears, though slightly variable in timing. Unlike the sharp GSI peak recorded in 2018, GSI values in 2019 remained moderately elevated across multiple months, suggesting an extended spawning window. It was also noted that there was another increase in GSI in December, reaching 2.29, which could point to a second, smaller spawning event or a group of fish maturing later than usual. Some developing and mature fish were still present in the late months, supporting this possibility. Overall, 2019 had a longer reproductive window compared to 2018, possibly due to environmental variations such as temperature or food availability.

In 2020, reproductive activity began earlier than in previous years, with elevated GSI values recorded as early as February, suggesting interannual variability in spawning onset. Consistent

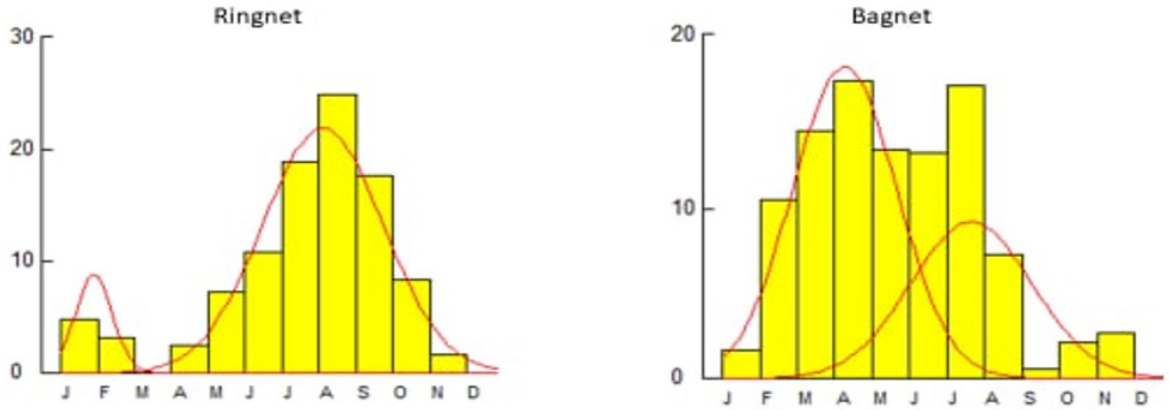

Figure 5. Recruitment pattern of *D. macrosoma* by gear from the fish landing sites in Narra and Brooke's Point, Palawan from January 2018 to December 2020.

peak spawning between April and May across years indicates a seasonally synchronized reproductive strategy typical of tropical small pelagic species. Reproductive activity started earlier than in previous years, with higher GSI values showing up as early as February (1.43) and March (1.37). This early rise was accompanied by more fish moving into the developing and mature stages. By April and May, many fish were in the ripe stage, indicating the main spawning period. Unlike in 2019, there was no second peak after May; both GSI and the number of mature fish declined steadily. This suggests that spawning was more concentrated in the first half of the year. The maturation process was possibly triggered by favorable environmental conditions such as warmer waters or better feeding opportunities early in the year.

Over the three years, *D. macrosoma* consistently showed a seasonal spawning pattern, with April to May being the peak months. In 2018, the pattern was sharp and clear, with a strong peak in May. In 2019, the pattern was a bit more spread out, with signs of extended or multiple spawning periods. In 2020, spawning onset occurred earlier relative to previous years, with elevated GSI values beginning in February and peaking in April. Post-peak decline in both mature-stage frequency and GSI suggests a more temporally concentrated reproductive period. These year-to-year changes highlight how flexible and responsive the species can be to environmental conditions, while still maintaining a general seasonal rhythm for reproduction.

3.3 Length at first maturity (L_m)

The estimated length at sexual maturity of female *D. macrosoma* was computed using 1,941 female samples. Results show that *D. macrosoma* reaches sexual maturity at a length of 15.81 cm or greater (Figure 5). Remarkably, this size signifies that the majority of the sampled individuals are identified as reproductive (mature and capable of spawning). The estimated L_m (15.81 cm TL) is below the mean length of asymptotic growth (L_∞), consistent with life-history expectations for short-lived pelagic species. However, given that the mean catch length in bagnet fisheries (14.85 cm) falls below L_m, growth and recruitment overfishing are likely occurring simultaneously.

Supporting this, the probability of capture (L_c50) routine from FiSAT II shows that the mean length at first capture (L_c) is 14.08 cm for bagnet and 15.68 cm for ringnet, with corresponding mesh sizes of 1.2 cm and 2.0 cm, respectively. In the case of the bagnet, L_c < Lm, meaning that many fish are captured before they can spawn. Although the ringnet L_c (15.68 cm) is close to L_m (15.81 cm), some juveniles are still vulnerable to capture. These findings demonstrate that the current gear selectivity contributes directly to growth and recruitment overfishing, highlighting the need for mesh-size regulation and length-at-capture management to allow more individuals to reach maturity and contribute to spawning biomass.

3.4 Population parameters

Natural mortality (M) ranged from 1.75 to 1.88, typical for small, fast-growing pelagic species such as scads. However, fishing mortality (F) was 2.71 for bagnet and 3.17 for ringnet, resulting in total mortality (Z) estimates between 4.46 and 4.94. These figures indicate that a large proportion of the population is being removed due to fishing pressure.

The calculated exploitation rates E were 0.61 for bagnet and 0.64 for ringnet, both of which exceed the commonly accepted limit reference point of 0.5.

This suggests that the stock is likely experiencing overfishing. Exploitation rates (E > 0.5) exceed the optimum exploitation benchmark (King, 2007), suggesting that fishing mortality surpasses biological replacement capacity. Continued fishing at current levels may reduce spawning biomass below safe biological limits.

The Y/R and B/R analyses generated from FiSAT II revealed distinct exploitation dynamics for the *bagnet* and *ringnet* fisheries targeting the study species. For *bagnet*, the estimated reference points were Emax = 0.751, E10 = 0.653, and E50 = 0.361, with a computed L_c = 14.08 cm corresponding to a 1.2 cm mesh size. For *ringnet*, the corresponding values were Emax = 0.773, E10 = 0.669, and E50 = 0.367, with L_c = 15.68 cm and a 2.0 cm mesh size. The observed exploitation rates derived from total mortality parameters were E = 0.61 for *bagnet* and E = 0.64 for *ringnet*.

Comparison of these observed E values with reference points indicates that both fisheries are operating above E50, the level generally considered biologically optimal for stock replacement, and also beyond the precautionary benchmark (E = 0.5) recommended by *Fisheries Biology, Assessment and Management*. Although current exploitation remains slightly below E10, suggesting that yield gains per recruit have not yet completely plateaued, the proximity of observed E to E10 implies that further increases in fishing pressure would yield minimal additional catch while accelerating biomass depletion.

The B/R curve demonstrated a progressive decline in biomass per recruit with increasing exploitation, with the relative biomass (B/B_0) falling below 40 % at E = 0.6. This indicates that the stock's spawning biomass is likely below safe biological limits under current exploitation levels.

Simulation of alternative L_c/L_∞ ratios to represent possible mesh-size adjustments showed that increasing the length at first capture (L_c) by 20–30 % would enhance B/R by 10–20 % while maintaining similar Y/R values. These results suggest that modest increases in mesh size would protect smaller individuals, increase spawning potential, and stabilize yield over time without major short-term losses. Better still is the strict implementation of FAO 155-1 which amended FAO 155, the minimum mesh size allowed for purse seines, ring nets, and bagnets is 1.9 cm (or 17 knots).

3.5 Other length-based models

The asymptotic length (L_∞) was estimated at 28.5 cm for fish caught with bagnet and 30.7 cm for those caught with ringnet. The species' growth coefficient (k), which ranged from 0.95 to 1.0 $year^{-1}$, indicates relatively rapid growth. Furthermore, the growth performance index (Φ′) supports the finding that *D. macrosoma* populations in the region are growing healthily and comparably to other areas in the Philippines.

The Spawning Potential Ratio (SPR), a measure of the remaining reproductive capacity of the stock under current fishing conditions, was estimated at 22% for bagnet and 26% for ringnet (Figure 7). Both values fall below the target reference point of 40%, with the SPR for bagnet nearing the critical threshold of 20%. This points to a significant reduction in reproductive output, especially in the bagnet fishery, and raises concerns about the long-term sustainability of the stock.

Additional indicators further reinforce these concerns. The fishing-to-natural mortality ratio (F/M) was 2.15 for bagnet and 2.01 for ringnet, more than

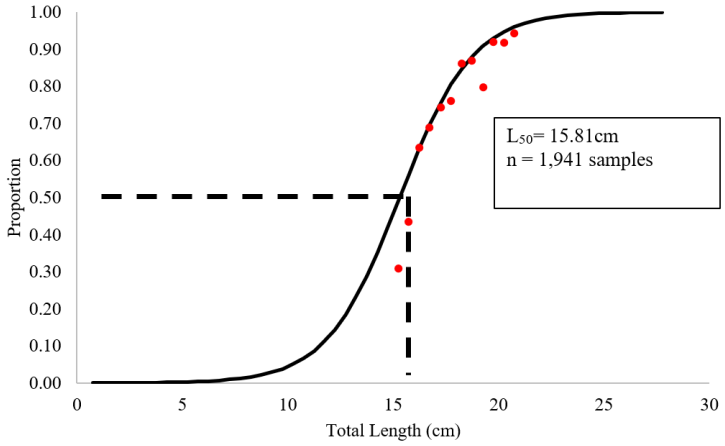

Figure 6. Estimated length at 50% maturity of female *D. macrosoma* from the fish landing sites in Narra and Brooke's Point, Palawan from January 2018 to December 2020.

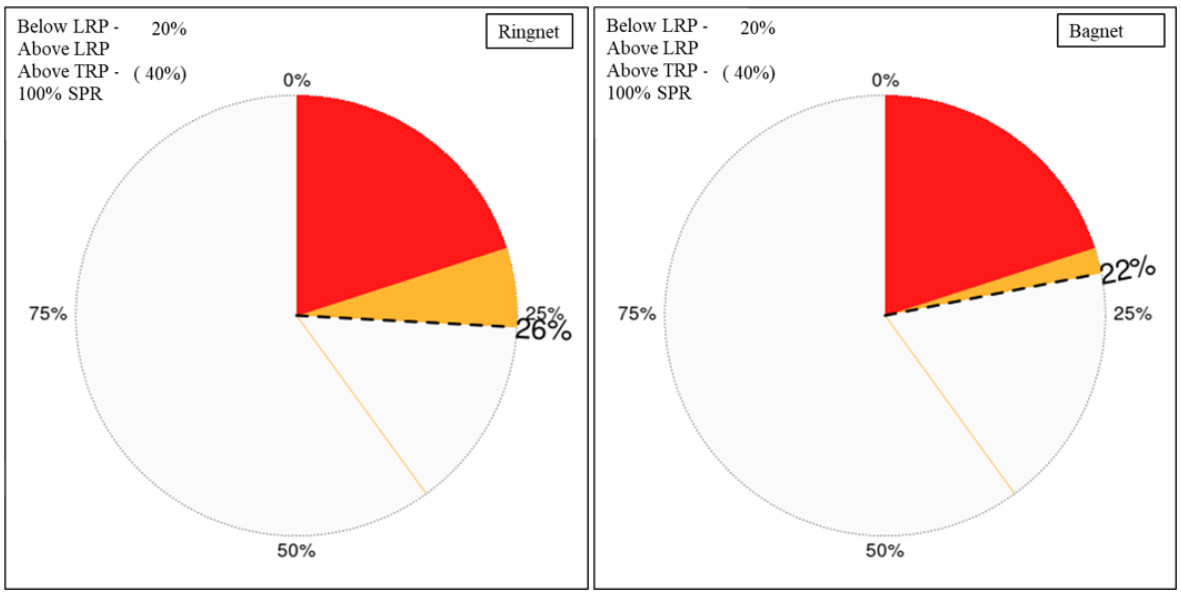

Figure 7. Spawning Potential Ratio (SPR) values of *D. macrosoma* caught in bagnet and ringnet from the fish landing sites in Narra and Brooke's Point, Palawan from January 2018 to December 2019.

twice the sustainable benchmark of ≤1.0. Meanwhile, the mean length of fish caught (LBAR) was 14.85 cm for bagnet and 17.89 cm for ringnet. Considering that the length at first maturity is estimated at 15.81 cm, it is evident that a substantial portion of the catch particularly in the bagnet fishery consists of immature individuals that may not have had the opportunity to reproduce.

The length-based indicators of Rainer Froese (2004) were applied to assess the stock status of *D. macrosoma* from 2018 to 2020 using length-frequency data. The results reveal clear signals of overexploitation based on the three diagnostic indicators: percentage of mature individuals, percentage of fish within ±10% of the optimum length (L_{opt}), and percentage of mega-spawners.

Froese results reveal that the proportion of mature individuals in the catch was consistently low throughout the study period, increasing from 10.4% in 2018 to 22.1% in 2019 and 28.9% in 2020 (Table 4). Despite the gradual upward trend, these values remain substantially below the 100% target reference level, which assumes that individuals are allowed to spawn at least once prior to capture. The mean lengths of fish in the catch (LBAR) were 14.85 cm for bagnet and 17.89 cm for ringnet. Considering that the estimated length at first maturity (L_m) is 15.81 cm TL, a substantial portion of the bagnet catch falls below the maturity threshold. The length-frequency distributions by gear (Figure 8) clearly show that bagnet landings are dominated by individuals below L_m, whereas ringnet catches include a relatively higher proportion of fish at or above the maturity size. This size-selectivity pattern indicates that the bagnet fishery exerts stronger pressure on pre-spawning cohorts.

The overlap between the modal length of bagnet catches and the immature size classes provides direct length-based evidence of recruitment overfishing. In contrast, the broader distribution of ringnet catches suggests comparatively higher retention of mature individuals, although exploitation levels remain elevated.

The percentage of fish captured at optimum length showed a marked increase over the three-year period, from 14.8% in 2018 to 26.1% in 2019 and 55.1% in 2020. The low values recorded in 2018 and 2019 indicate pronounced growth overfishing, where individuals are harvested before reaching the length that maximizes cohort biomass. The substantial increase in 2020 suggests partial improvement in size selectivity or shifts in fishing patterns; however, the value remains below the ideal reference level. This indicates that while some recovery in size composition may be occurring, growth overfishing persists.

The proportion of mega-spawners (>110% of *L*opt) remained critically low throughout the study, with values of 3.6% in 2018, 9.4% in 2019, and 4.1% in 2020. These figures are far below the recommended 30–40% indicative of a healthy size structure and even below the 20% threshold signaling serious concern. The scarcity of large individuals suggests severe size and age truncation in the population. The continued removal of large, highly fecund fish reduces reproductive potential and resilience to

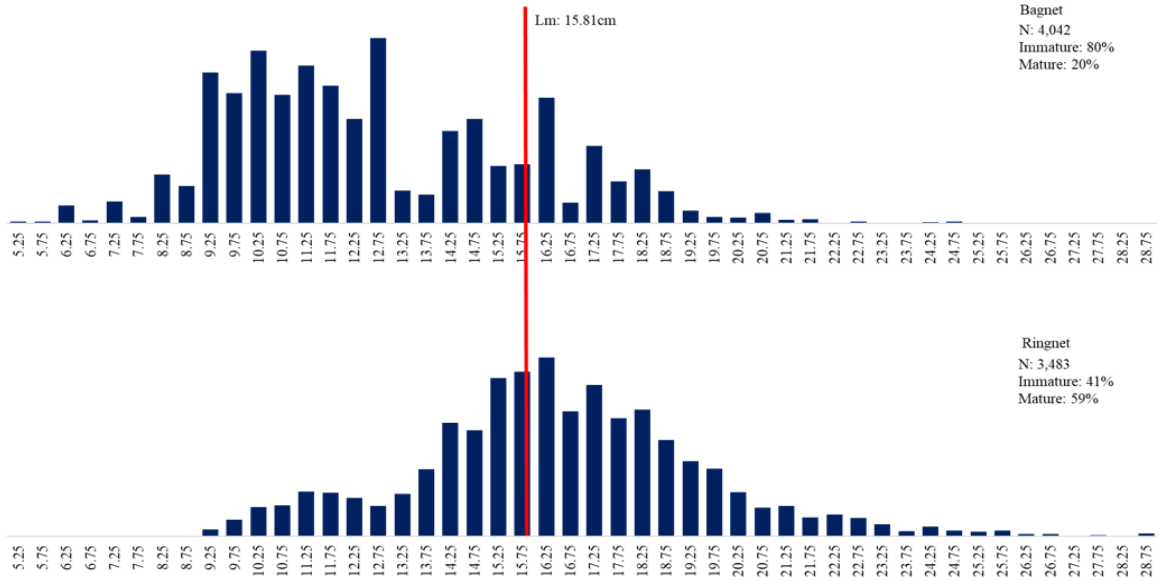

Figure 8. Length frequency distribution per gear showing the length at first maturity of *D. macrosoma* from the fish landing sites in Narra and Brooke's Point, Palawan from January 2018 to December 2020.

environmental variability and increases vulnerability to stock depletion under sustained fishing pressure.

Overall, the three Froese indicators collectively demonstrate that the stock of *D. macrosoma* from 2018 to 2020 was subjected to both recruitment and growth overfishing, accompanied by significant size truncation. Although improvements in the proportion of fish at optimum length were observed in 2020, the persistently low percentages of mature individuals and mega-spawners highlight ongoing exploitation pressure. These findings underscore the need for strengthened management measures, including improved size selectivity, strict enforcement of minimum mesh regulations (i.e., FAO 155-1), and protection of spawning stocks to enhance reproductive output and long-term sustainability.

4. DISCUSSION

4.1 Sex ratio

Sex ratio of *D. macrosoma*, results showed that there were more female than male samples with a ratio of 1:1.17. indicating that in every male there are approximately 1.17 females present. Statistical analysis revealed a significant deviation from the expected 1:1 ratio ($\chi^2 = 42.17, p < 0.05$), indicating female dominance in the sampled population confirming a female biased population structure. This dominance of females may be associated with the species' reproductive activity, as reflected by the GSI pattern. The peak GSI observed in May corresponds to the height of the spawning season, during which mature females are more active and likely more susceptible to capture as they form spawning aggregations. The temporal coincidence between higher GSI values and the increased proportion of females suggests that the reproductive cycle influences the observed sex ratio dynamics. Similar studies in the Philippines conducted by Tiews et al. (1970) in Manila Bay recorded a sex ratio of more females than males; Calvelo et al. (1991) in Calagua Island, Lamon Bay, also recorded a dominance of females over male with a sex ratio of 1.2:1. Likewise, study of Prihartini et al. (2007) in Javanese waters, Indonesia also reported a higher number of females than males, with 55.85% more female than male fish (13.18>6.64), and a sex ratio of 1:2 in Banda Aceh, Indonesia (Senen et al. 2011). Sex ratio could be influenced by the availability of food (Nikolsky 1963; 1969). When food is abundant, females predominate, with the situation inverting in regions, where food is limited. Feeding activity, in this case, would be influencing metabolism through hormonal activity, resulting in changes in production of individuals of a given sex. Likewise, the high proportion (52%) of undetermined sex likely reflects the inclusion of juvenile individuals and/or limitations of macroscopic staging, particularly for early maturity phases. Future studies incorporating histological validation and environmental data analysis (e.g., SST and chlorophyll-a for primary productivity and food availability) are recommended to improve accuracy.

4.2 Spawning period

Over the three-year study period (2018–2020), *D. macrosoma* exhibited a relatively consistent seasonal pattern in its reproductive activity (Figure 3), with peak spawning generally occurring between April and May. No samples collected in November 2019, October 2020, November 2020, and in December across all three years, due to fishing cessation associated with seasonal management measures and adverse weather conditions.

This decision aligned with a closed fishing season initiative in northeastern Palawan, designed to support undisturbed spawning, a proactive move toward sustainable fisheries management. Additionally, this period overlaps with the northeast monsoon, when rough sea conditions naturally limit fishing operations. In 2020, further restrictions caused by the COVID-19 pandemic also affected data collection.

The reproductive peak was marked by the presence of mature, Stage IV (ripe) females and higher mean GSI values. These patterns align with earlier findings on small pelagic fishes such as *Sardinella gibbosa* and *Sardinella fimbriata*, which also exhibit major spawning activity in March and April, with secondary peaks later in the year (Rivera et al. 2017).

In 2019, reproductive activity exhibited a more prolonged distribution compared to 2018, with GSI values remaining high from February to May and a secondary increase observed in July. This extended window mirrors trends seen in the Babuyan Channel, where *D. macrosoma* showed reproductive peaks in May (Rivera et al. 2017). Such shifts may be driven by environmental conditions, including sea surface temperature (SST) and food availability (Chlorophyll-a), both of which influence gonad development.

In 2020, spawning activity started earlier than in previous years (Figure 3), with GSI values rising as early as February and peaking in April. A similar early onset of spawning has been reported in southern Kyushu, Japan, where *D. macrosoma* typically spawns between May and August (Ohshimo et al. 2014). Environmental variability, including sea surface temperature and productivity changes, may have influenced interannual differences in spawning onset.

Across all years, the regular appearance of ripe females during periods of high GSI supports the reliability of GSI as a useful indicator of reproductive readiness. At the same time, the year-to-year differences in timing and intensity of spawning suggest that *D. macrosoma* is capable of adjusting its reproductive cycle in response to changing conditions, a trait that may be essential for its resilience in the face of environmental fluctuations.

These findings are consistent with recent studies in other regions of the Philippines. For instance, *D. macrosoma* populations in the Babuyan Channel were found to spawn multiple times throughout the year, particularly from February to May and again from July to November (Villarao and Encarnacion 2023). The length of the spawning season may be influenced by the abundance of planktonic prey (Chang et al. 2009; Jose et al. 2015), along with other nutrients and zooplankton dynamics in the area (Villarao and Encarnacion 2023). Similarly, a May spawning peak was observed in Romblon Pass (Gonzales et al. 2021), coinciding with warmer seasonal temperatures. In southwest Palawan, spawning tends to begin about two months earlier than in the northeast, where peaks typically occur from November to January. In the broader MIMAROPA region, the most common spawning months are May and December, while in Romblon waters, May, October, and December are most prominent (Gonzales et al. 2021). Overall, these regional differences point to a reproductive pattern that, while broadly similar across locations, is flexible enough to adapt to local environmental cues. Interannual variation in spawning timing may be associated with variability in sea surface temperature (SST) and primary productivity, which influence gonadal development and larval survival in small pelagic fishes.

The recruitment analysis based on FiSAT revealed that *D. macrosoma* exhibits two recruitment pulses under both bagnet and ringnet operations, indicating a consistent seasonal reproductive pattern across gears. The recruitment pulse observed in July-August for both gears corresponds closely with the peak gonadosomatic index (GSI) recorded in May, signifying that spawning activity during the late dry season leads to the influx of juveniles in midyear. The minor recruitment pulse detected in July-August for bagnet and January-February for ringnet suggests that a smaller, secondary spawning episode occurs earlier and mid in the year, as also indicated by the presence of developing and mature individuals during the first quarter.

The slight differences in the timing of recruitment pulses between the two gears may reflect differences in fishing depth, area, and selectivity, with ringnets typically operating farther offshore where

slightly older juveniles are encountered. Nonetheless, the synchronization of the main recruitment pulse across both gears underscores a strong seasonal signal in the reproductive dynamics of *D. macrosoma*.

Comparable recruitment and spawning patterns have been reported for other *Decapterus* species in Philippine waters. Dalzell and Ganaden (1994) described similar biannual recruitment pulses for *Decapterus* species, which they attributed to environmental variability and the influence of monsoonal transitions. Corpuz et al. (1985) observed a comparable reproductive pattern for *D. russelli* in the Visayan Sea, where peak spawning occurred during the late dry season, followed by recruitment at the onset of the southwest monsoon. Moreover, the National Stock Assessment Program (Santos et al. 2017) highlighted that small pelagic species, including *Decapterus* spp., typically exhibit seasonal recruitment peaks closely aligned with the prevailing monsoonal cycles.

These results suggest that *D. macrosoma* exhibits a well-defined seasonal reproductive cycle, characterized by a major spawning peak during April–May and corresponding recruitment pulses in July–August. The presence of a secondary recruitment pulse earlier in the year further indicates multiple spawning events within an annual cycle. Such periodicity likely enhances recruitment stability and may represent an adaptive reproductive strategy that promotes larval survival and population persistence under variable environmental conditions.

4.3 Length at first maturity (Lm)

The result of this study estimated the length at which 50% of the female *D. macrosoma* reaches sexual maturity at 15.81 cm TL (Figure 6). The values obtained were closer to the data from Rada et al. (2019) in San Fernando, Romblon at 15.29 cm, from Widodo (1991) in the Java Sea with the length at maturity of 15.50 cm. Correspondingly, the values obtained by Balasubrahmanian and Natarajan (2000) in India, reported that female *D. macrosoma* attained maturity at 15.70 cm. The length of maturity values from this study is lower than the values obtained by Shiraishi et al. (2010) in Southern Kyushu, Japan, with a value of 23.20 cm, signifying that females in this particular population are reaching sexual maturity at smaller size than expected. Some results have the larger mature lengths such as the study of Gonzales et al. (2021) in Tablas Island, Romblon at 20.36 cm, with closer data obtained from Palawan wherein the length at maturity of *D. macrosoma* was 17.2 cm in 2016, 16.9 cm in 2017, 17.7 cm in 2018, and 17.1 cm in 2019 (DA-DILG 2015).

These lower values can be attributed to environmental factors, habitat and biological characteristics. Rada et al. (2019) in their study affirmed that sexual maturity can be influenced by the seawater temperature; growth of fishes in areas with high water temperature is faster and the size of sexual maturity is smaller than the areas of with low water temperature. It is noted that the Philippines is located in the tropical region with warmer average seawater temperature, thus influencing the sexual maturity of *D. macrosoma.* The impact of intense exploitation is reflected in the decline of length. Larger individuals find refuge in unfished areas.

4.4 Population parameters

The estimated natural mortality (M) values ranging from 1.75 to 1.88 align with those reported for small, fast-growing pelagic species like *D. macrosoma* (Villarao and Encarnacion 2023). For instance, a study in Antique, Philippines, reported an M of 1.88 $year^{-1}$ for this species (Magallanes et al. 2022). However, the fishing mortality (F) rates were 2.71 for bagnet and 3.17 for ringnet are notably higher, leading to total mortality (Z) estimates between 4.46 and 4.94. These elevated F values suggest that fishing is a significant contributor to overall mortality in the population.

The exploitation rates (E) calculated at 0.61 for bagnet and 0.64 for ringnet exceed the commonly accepted limit reference point of 0.5, indicating potential overexploitation. This is consistent with findings from Antique, where an E of 0.60 was reported for *D. macrosoma* (Magallanes et al. 2022). Such high exploitation rates can lead to stock depletion if not managed appropriately.

The yield-per-recruit and biomass-per-recruit analyses provide quantitative evidence that the present exploitation levels of the studied stock, particularly under *bagnet* and *ringnet* operations, exceed biologically sustainable thresholds. Observed exploitation rates (E = 0.61 and E = 0.64) surpass the optimum exploitation rate (E50 = 0.361) and the conventional limit reference point (E = 0.5), indicating that fishing mortality currently exceeds the stock's replacement capacity. Similar findings have been reported in other tropical small-pelagic fisheries where sustained high E values were associated with reduced biomass and recruitment potential (Santos et al. 2017).

The proximity of the observed E to E10 suggests that the fishery is nearing the point of diminishing returns, where yield gains from additional effort would be negligible, but the risk of recruitment overfishing would increase sharply. The observed decline in B/R supports this interpretation, indicating reduced

spawning biomass and limited recovery potential under present fishing pressure.

Adjusting the length at first capture (Lc/L_{∞}) a proxy for mesh-size regulation appears to be an effective management option. Simulation results indicate that increasing Lc by 20–30 % (for example, by adopting slightly larger mesh sizes (about 2–2.5 cm) or using escape panels) would allow more individuals to reach maturity before capture. This adjustment would increase spawning biomass (B/B_0), enhance recruitment stability, and sustain yields in the long term.

These findings highlight the need for effort control and gear regulation. Simulation of alternative Lc/L_{∞} ratios to represent possible mesh-size adjustments showed that increasing the length at first capture (Lc) by 20–30 % would enhance B/R by 10–20 % while maintaining similar Y/R values. These results suggest that modest increases (20–30%) in mesh size (about 2-2.5 cm) would protect smaller individuals, increase spawning potential, and stabilize yield over time without major short-term losses. Otherwise, strict implementation of FAO 155-1 which amended FAO 155, the minimum mesh size allowed for purse seines, ring nets, and bagnets is 1.9 cm (or 17 knots). Reducing exploitation toward or below E = 0.5, together with the implementation of minimum mesh-size restrictions, could restore the stock to safer biological limits. Continuous monitoring through Y/R–B/R analyses is recommended to assess the effects of these management measures and refine exploitation targets under changing environmental and socio-economic conditions.

Fishing mortality (F) and exploitation rate (E) can be effectively reduced through a combination of targeted management interventions. One primary measure is increasing mesh size to ensure that the length at first capture (Lc) exceeds the length at first maturity (Lm), thereby allowing individuals to reproduce at least once before being harvested. Effort limitation strategies, such as regulating the number of vessels or imposing fishing day restrictions, can further reduce overall fishing pressure. Aligning or expanding the seasonal closure to coincide with the April–May peak spawning period would enhance protection of spawning biomass during its most vulnerable stage. In addition, spatial protection of identified nursery grounds can safeguard juvenile cohorts and strengthen recruitment. Where administratively feasible, the implementation of catch quotas or total allowable catch (TAC) limits may provide an additional control mechanism to prevent excessive harvest.

Simulation results suggest that increasing Lc by approximately 20–30% could substantially reduce effective fishing mortality by allowing a greater proportion of the population to spawn at least once prior to capture. This adjustment is projected to increase spawning potential ratio (SPR) to levels exceeding the 30–40% management reference target, thereby improving stock resilience and long-term sustainability.

4.5 Length-based parameters

The asymptotic lengths (L_{∞}) estimated at 28.5 cm for bagnet-caught and 30.7 cm for ringnet-caught individuals are within the range reported in other regions. For example, studies have reported L_{∞} values of 26.18 cm in Antique (Magallanes et al. 2022) and up to 34.25 cm in South Sulawesi, Indonesia (Asni et al. 2019). The growth coefficients (K) ranging from 0.95 to 1.00 $year^{-1}$ indicate a relatively rapid growth rate, which is characteristic of small pelagic species. The growth performance index (Φ') further supports healthy growth patterns, with values comparable to those observed in other Philippine populations (Table 3).

The Spawning Potential Ratio (SPR) values of 22% for bagnet and 26% for ringnet are below the target reference point of 40%, with the bagnet value approaching the critical threshold of 20% (Figure 6). This indicates a significant reduction in reproductive potential, particularly in the bagnet fishery, which may compromise the sustainability of the stock. Similar concerns have been raised in other studies, emphasizing the need for effective management strategies to ensure the long-term viability of *D. macrosoma* populations (Magallanes et al. 2022).

The fishing mortality to natural mortality ratios (F/M) of 2.15 for bagnet and 2.01 for ringnet exceed the sustainable benchmark of ≤1.0, indicating fishing mortality substantially surpasses natural mortality. The mean lengths of fish in the catch (LBAR) were 14.85 cm for bagnet and 17.89 cm for ringnet. Given that the length at first maturity (Lm) is estimated at 15.81 cm, a substantial portion of the catch, especially from the bagnet fishery, consists of individuals that may not have reached reproductive maturity. This practice can lead to recruitment overfishing, where the stock's ability to replenish is compromised.

The gear-specific length-frequency distributions (Figure 8) further clarify the mechanism underlying recruitment overfishing. The dominance of sub-mature individuals in bagnet catches indicates that fishing mortality is concentrated on pre-

Table 3. Comparison of estimated growth and mortality parameters of *D. macrosoma* from various studies in the Philippines and other countries.

Area	L_∞ (cm)	L_{max} (cm)	K (yr^{-1})	σ'	M (yr^{-1})	F (yr^{-1})	Z (yr^{-1})	E	Source
Southwest Sulu Sea (Bagnet)	28.5	25.5	0.95	2.89	1.75	2.71	4.46	0.61	Present study
Southwest Sulu Sea (Ringnet)	30.7	28.5	1	2.97	1.78	3.17	4.94	0.64	Present study
Antique	26.18	22.42	1	2.836	1.88	2.78	4.66	0.6	Present study
Philippines	23.0 - 33.0	-	0.50-1.26	-	-	-	-	-	Ingles and Pauly (1984)
Manila Bay	31.5	-	1	-	1.33	2.41	3.74	-	Ingles and Pauly (1984)
Palawan	30	-	0.74	2.82	1.47	4.32	5.79	0.75	Ingles and Pauly (1984)
Manila Bay	26.9 - 33.0	-	0.45-0.80	-	-	-	-	-	Corpuz et al. (1985)
Leyte Gulf	27.3	27.62	1.4	2.14	1.88	2.29	4.67	-	Lavapie-Gonzales et al. (1997)
Visayan Sea	31.3	29.57	-	-	-	-	-	-	Lavapie-Gonzales et al. (1997)
Guimaras Strait	31.7	30.02	-	-	-	-	-	-	Lavapie-Gonzales et al. (1997)
Samar Sea	27	27.11	-	-	-	-	-	-	Lavapie-Gonzales et al. (1997)
Camotes Sea	28	30.02	1.6	-	2.47	2.66	5.13	0.51	Lavapie-Gonzales et al. (1997)
Camotes Sea	27.56	-	-	-	-	-	-	0.71	Belga et al. (2018)
Davao Gulf	29.9	31.21	-	-	-	-	-	-	Lavapie-Gonzales et al. (1997)
South Sulu Sea	27.8	26.8	1.2	-	2.45	4.8	7.25	0.72	Lavapie-Gonzales et al. (1997)
Moro Gulf/Illana Bay	21.4	24.48	2.3	-	3.28	0.97	4.25	0.2	Lavapie-Gonzales et al. (1997)
Tawi-Tawi	24.9	-	0.77	2.68	1.59	1.9	3.49	0.54	Aripin and Showers (2000)
Indonesia	25.6	-	1.05	-	-	-	-	-	Sadhotomo and Atmadja (1985)
Thailand	23.2 - 27.5	-	1.05	-	-	-	-	-	Anon (1985)
Java sea, Indonesia	22.4 - 26.5	-	0.86 1.31	-	-	-	-	-	Atmadja (1988)
Java Sea, Indonesia	23.1 - 25.6	-	0.7-1.1	-	-	-	-	-	Widodo (1988)
Vinzhuijam Coast, India	25.7	-	0.9	-	-	-	-	-	Balasubramanian (1997)
Suez, Egypt	26.97	-	0.56	-	-	1.11	-	-	Mehanna (1999)
Karnataka Coast, India	23.8	-	0.75	-	-	-	-	0.2	Rohit and Shanbhogue (2005)

reproductive size classes, thereby reducing spawning biomass before individuals contribute to recruitment. In contrast, ringnet catches exhibit a wider size spectrum, including individuals above Lm, although exploitation rates remain beyond sustainable limits. The size truncation observed in Figure 7 is consistent with the low proportions of mature individuals and mega-spawners reported in the Froese indicators (Table 4), reinforcing the diagnosis of combined recruitment and growth overfishing.

These findings support the implementation of precautionary management measures to prevent further stock depletion. Potential measures include implementing size limits to ensure fish reach maturity before capture, regulating fishing effort to maintain exploitation rates within sustainable limits, and establishing closed seasons or protected areas during peak spawning periods to enhance reproductive success. Continuous monitoring and research are essential to adaptively manage the fishery and ensure the long-term sustainability of *D. macrosoma* populations.

Beyond fishing pressure, interannual variability in spawning timing and intensity observed during the study period suggests potential environmental modulation of reproductive processes. Small pelagic species such as *D. macrosoma* are known to respond rapidly to changes in oceanographic conditions, particularly sea surface temperature (SST) and primary productivity. Variations in SST influence metabolic rates, gonadal development, and spawning onset, while chlorophyll-a concentration serves as a proxy for primary productivity and plankton availability, which directly affect larval survival and recruitment success. Integrating fisheries monitoring data with spatial mapping of SST and chlorophyll-a would provide valuable insights into the environmental drivers shaping spawning dynamics and recruitment variability in the Southwest Sulu Sea. Such ecosystem-based assessment approaches

Table 4. Froese indicators of *D. macrosoma* from the fish landing sites in Narra and Brooke's Point, Palawan from January 2018 to December 2020.

Year	2018	2019	2020
Percent Mature	10.4	22.1	28.9
Percent within ±10% of L_{opt}	14.8	26.1	55.1
Percent Mega-spawners	3.6	9.4	4.1

are essential for improving predictive capacity and strengthening adaptive fisheries management under changing climatic conditions.

5. CONCLUSION

The findings of this study indicate that *D. macrosoma* in the Southwest Sulu Sea is currently subjected to fishing pressure beyond sustainable biological limits. Elevated fishing mortality, exploitation rates exceeding the precautionary threshold (E > 0.5), spawning potential ratios below the 40% target reference level, and severe size truncation collectively demonstrate recruitment and growth overfishing.

The substantial proportion of immature individuals in the catch; particularly in bagnet fisheries further indicates that spawning biomass is being reduced before individuals contribute to reproduction. Although growth parameters reflect a relatively fast-growing species typical of small pelagic fishes, this life-history advantage does not offset sustained high fishing mortality. Continued removal of pre-spawning cohorts compromises reproductive output and long-term stock resilience.

Immediate implementation of biologically grounded management measures is necessary. These include strict enforcement of minimum size limits (i.e., FAO 155-1) and gradual mesh size limit increase, aligned with the estimated L_{50}, improving gear selectivity to reduce juvenile capture, regulating fishing effort, and strengthening seasonal or area-based closures during the April–May peak spawning period. Such measures would enhance reproductive capacity and promote stock rebuilding.

In addition, the integration of sea surface temperature (SST) and chlorophyll-a analysis mapping is recommended to better understand the environmental drivers influencing spawning dynamics, recruitment variability, and spatial distribution of *D. macrosoma*. Incorporating oceanographic indicators into routine fisheries monitoring would strengthen ecosystem-based management and improve adaptive responses to climate-driven changes and variability in productivity.

Sustained monitoring under the NSAP, combined with precautionary and environmentally informed management, will be essential to ensure the long-term sustainability of *D. macrosoma* and the fisheries-dependent communities of the Southwest Sulu Sea.

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AUTHOR CONTRIBUTIONS

Gonzales LM: Conceptualization, Methodology, Formal Analysis, Writing Reviewing and Editing. **Candelario MB:** Conceptualization, Formal Analysis, and Supervision. **Palla HP:** Conceptualization, Formal analysis, and Writing - Review & Editing. **Villaflor EM:** Data processing and analysis, Methodology and Formal Analysis.

CONFLICT OF INTEREST

The authors declare no competing interests.

ETHICS STATEMENT

This study involved no human subjects. Fish samples were obtained from commercial landings under routine monitoring protocols of the National Stock Assessment Program (NSAP).

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